BBC RD 1987/12

BBC Research Department Report

September 1987

ACCOMMODATING THE RESIDUE OF PROCESSED OR COMPUTED DIGITAL VIDEO SIGNALS WITHIN THE 8 BIT CCIR RECOMMENDATION 601

M.G. Croll, B.Sc., A.R.C.S., V.G. Devereux, M.A., and M. Weston, B.A.

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

BBC RD 1987/12

UDC 621.3.037.372.2 : 621.397.132

ACCOMMODATING THE RESIDUE OF PROCESSED OR COMPUTED DIGITAL VIDEO SIGNALS WITHIN THE 8 BIT CCIR RECOMMENDATION 601

M.G. Croll, B.Sc., A.R.C.S., V.G. Devereux, M.A., and M. Weston, B.A.

Summary

A method is described for rounding down the number of bits in a digital video signal in such a manner that the resulting quantising errors have a lower visibility than that of errors given by simple truncation. In particular, it avoids the generation of visible contours when the quantising resolution is reduced to 8 bits. It is relevant to digital video processes such as fading and filtering where additional lower order bits are generated prior to an 8-bit interface. It can also be used in the synthetic generation of video signals.

Systems employing the method of rounding described here have been found to exhibit a more noise-like and subjectively less distracting quantisation effect than where simple truncation is applied after digital processes.

Issued under the Authority of

M.E.B. Moffat

Head of Research Department

Research Department, Engineering Division,
BRITISH BROADCASTING CORPORATION

(PH-289)

September 1987

It uses SI units in accordance with B.S. document
PD 5686.

ACCOMMODATING THE RESIDUE OF PROCESSED OR COMPUTED DIGITAL VIDEO SIGNALS WITHIN THE 8 BIT CCIR RECOMMENDATION 601

M.G. Croll, B.Sc., A.R.C.S., V.G. Devereux, M.A.,
and M. Weston, B.A.

ACCOMMODATING THE RESIDUE OF PROCESSED OR COMPUTED DIGITAL VIDEO SIGNALS WITHIN THE 8 BIT CCIR RECOMMENDATION 601

M.G. Croll, B.Sc., A.R.C.S., V.G. Devereux, M.A., and M. Weston, B.A.

1. INTRODUCTION

Many digital video processes generate additional bits which are of lower significance than the 8-bit digital video signals that are applied to these processes. Examples are (a) digital video filtering where a large number of multiplication stages are cascaded and several of the fractional bits produced at each stage in the filter are conveyed to the output of the filter, and (b) digital video faders where an 8-bit signal may cause a very large number of fractional bits to be generated. If these fractional bits are simply discarded, the signal may appear distorted with visible contours appearing in plain areas of a picture. This is particularly noticeable towards the end of a fade to black and is evidence that an effective form of rounding must be applied to avoid systematic errors which visibly distort the signal.

A further requirement for effective rounding arises with electronic signal generators such as graphics drawing devices, test signal generators and signal computing systems. In such equipment, it can be beneficial to generate additional fractional bits and then apply rounding before the signal is output. Otherwise, noiseless mathematically generated signals may step visibly from one 8-bit quantum step to another where a gradual linear change of level was intended. Contouring effects of this type are not normally produced by 8-bit A/D conversion of signals from other picture sources such as TV cameras because of the randomising effect of the inherent noise in the source.

The method described in the Report can be summarised as "never throw anything away". This is achieved by preserving the residue of any truncation and adding it to the next digital video sample. This process breaks up the contouring efects which can be caused by simple truncation and replaces them with much less visible noise-like quantising errors.

Similar techniques are described in Ref. 1. In this case the requirement was for accurate frequency conversion using a series of interconnected counters. Lower stages of the counters accommodated a residue which was accumulated until it produced a carry so that integrated over a period the precise frequency ratio was maintained.

The technique described in this Report has been successfully applied in the BBC since about 1974. It has have been found capable of overcoming digital processing inaccuracies which lead to the generation of contours and visible noise patterns and substituting random noise-like effects with a predominantly high frequency characteristic whose visibility is less than that of the equivalent flat spectrum noise.

2. ERROR FEEDBACK

Error feedback techniques were probably first applied to digital video coding by Cutler in 1960[2]. Other early work was carried out by Kimme and Kuo[3] and Brainard[4]. An example given by Cutler illustrating the basic principles of the technique is illustrated in Fig. 1. In this arrangement, a coding error E_n given by the difference between the input and output of a quantiser is fed back via a delay and added to the next input sample. This corrects any DC error since each error is presented to the quantiser as an equal and opposite error one sample later. If the error feedback is insufficient to affect the decision of the quantiser, it is accumulated in the loop containing the adder, subtractor and delay and added to later samples.

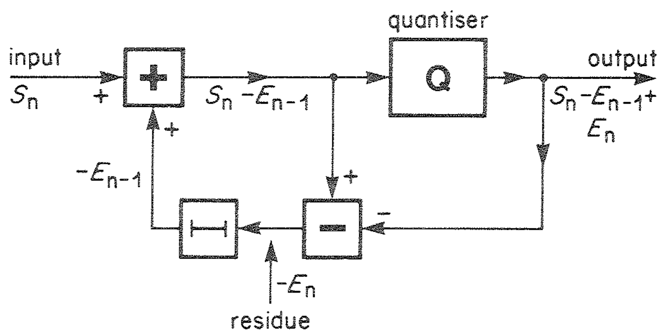


Fig. 1 - Quantiser with error feedback.

S_n is current input sample value.
E_n is coding error for sample S_n.
E_{n-1} is coding error for previous sample S_{n-1}.

In the original work, error feedback was applied to analogue-to-digital conversion processes. It is not normally used in this way because of instrumental difficulties. This Report is concerned with a similar process applied to a purely digital signal[5].

Fig. 2 shows the implementation of an error feedback system where 16 bits are reduced to 8 bits. It can be seen that the number of components required is small. Its principle of operation is that where a signal is truncated to fewer bits, the fractional bits are accumulated sample by sample until a carry bit is generated which is then added to the least significant bit being output.

The most significant effect of the above processes is as follows:

In large plain areas of a picture where the video signal excurses only a few quantum steps, a quantising process may generate contours which are more visible than the random quantum errors generated by larger signal excursions.

In these cases, the error feedback system causes the contours to be replaced with much less visible random changes between two adjacent quantum steps. This is illustrated in Fig. 3 for a linear ramp input signal.

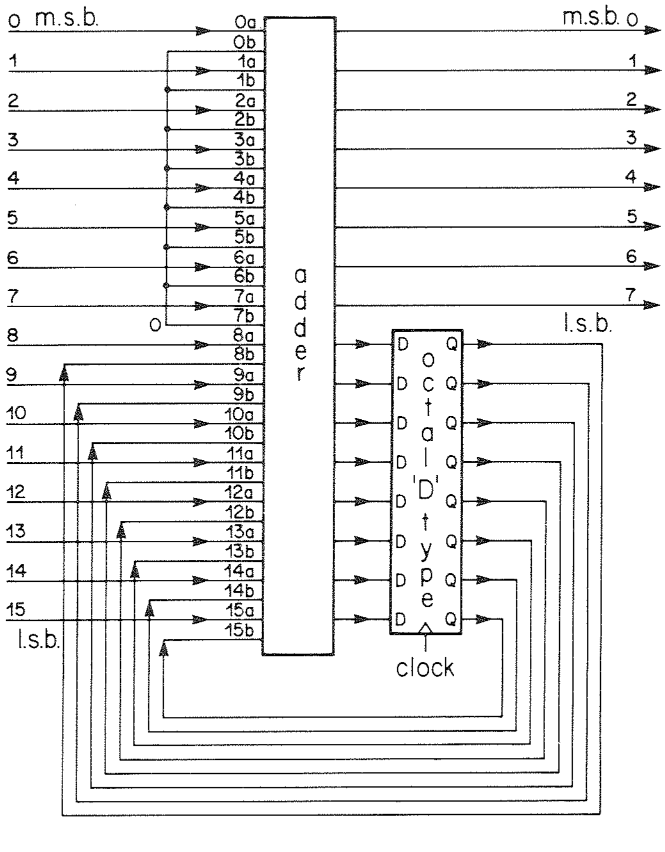


Fig. 2 - Error feedback rounding of 16 bits to 8.

The mark-to-space ratio of the variations in the output is determined by the relationship between the input level and the two adjacent output levels. This is illustrated in Fig. 4 for a constant input level which is xQ above an output level where, Q is the output quantum step size. The resulting output waveform remains at the lower level for a duration xT during each repetition period T of the output waveform. Thus the mean level of the output signal is equal to that of the input signal.

In practice, the time between changes in the output level is quantised into multiples of the sampling periods with the smaller of the two intervals xT and $(1-x)T$ being equal to one sample period. If the required duration of the larger of these two intervals is not an integer number of sampling periods, it oscillates between the two closest numbers of sampling periods in such a manner that its mean value is correct.

In addition to its beneficial effect on slowly changing signals, the quantising noise resulting from error feedback is less visible than the noise produced by simple truncation even when no contouring effects are involved. This is because the error feedback noise has a predominantly high frequency spectrum. Fig. 5 shows this quantisation spectrum for video signals sampled at 13.5 MHz and compares it with the white noise spectrum that would be produced if a video signal were quantised in the normal way. The weighted* spectra are also shown; it can be seen that the use of error feedback reduces the total weighted noise power in a 0 to 5.0 MHz bandwidth, the reduction ratio being about 53%.

3. SUBJECTIVE EFFECT OF USING ERROR FEEDBACK

The effects of error feedback are illustrated in Figs. 6 and 7. The number of bits per sample have been reduced from 8 bits to only 3 or 4 bits to ensure that the quantising effects are easily visible. Fig. 6 shows the effect with a conventional test card. Where the 8 bit quantised signal is truncated to a 3-bit quantised signal by simply discarding the lower five significant bits, a very visible distortion of the picture is produced (see Fig. 6(b)). Such contours may additionally draw attention to themselves where moving picture sequences are processed and slight changes in level cause contours to move across otherwise smooth areas. Where the error feedback process is applied at the point of truncation from 8 bits to 3 bits, the result is a noise-like characteristic and there is no coherence in the quantisation distortion (see Fig. 6(c)).

* CCIR 567 Weighting

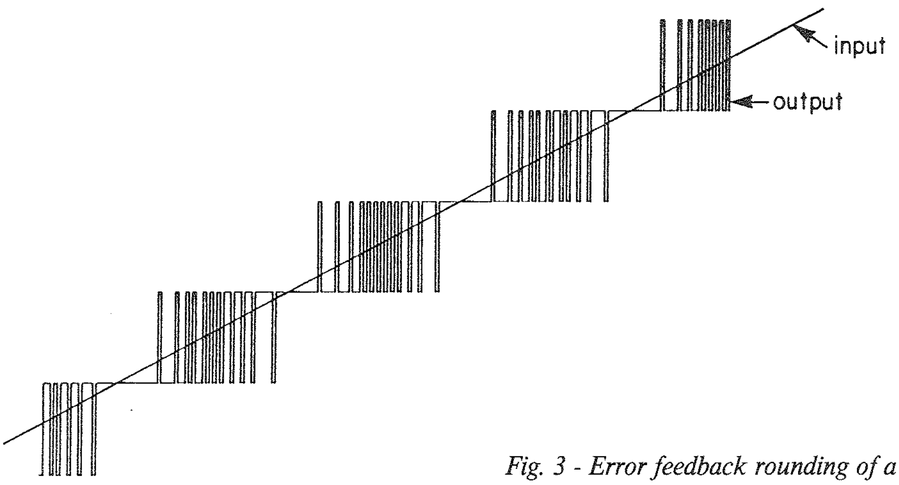


Fig. 3 - Error feedback rounding of a ramp signal.

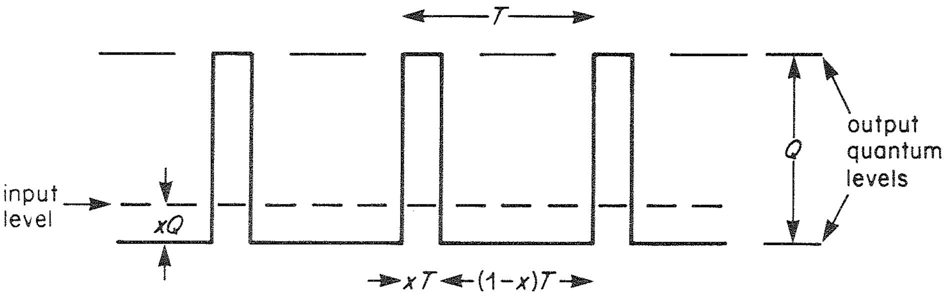


Fig. 4 - Details of error feedback rounding.

Applying the process to an artificially generated ramp signal shows that quantisation by simple truncation to 4 bits introduces highly visible coherent contouring (see Fig. 7(b)). Although with error feedback the distortion is coherent, the visibility of the quantising effect remains substantially reduced and the fine patterning is only just visible (see Fig. 7(c)). The precise pattern generated in this illustration is determined by the original ramp slope and the fact that the error feedback accumulator is never reset and therefore starts each new line with the residue of the last truncation from the previous line.

Fig. 8 shows photographs taken from an oscilloscope of the ramp waveform. Note that the output waveform shown in Fig. 8(c) differs from the ideal waveform of Fig. 3 because it has passed through a low-pass filter in a D/A converter.

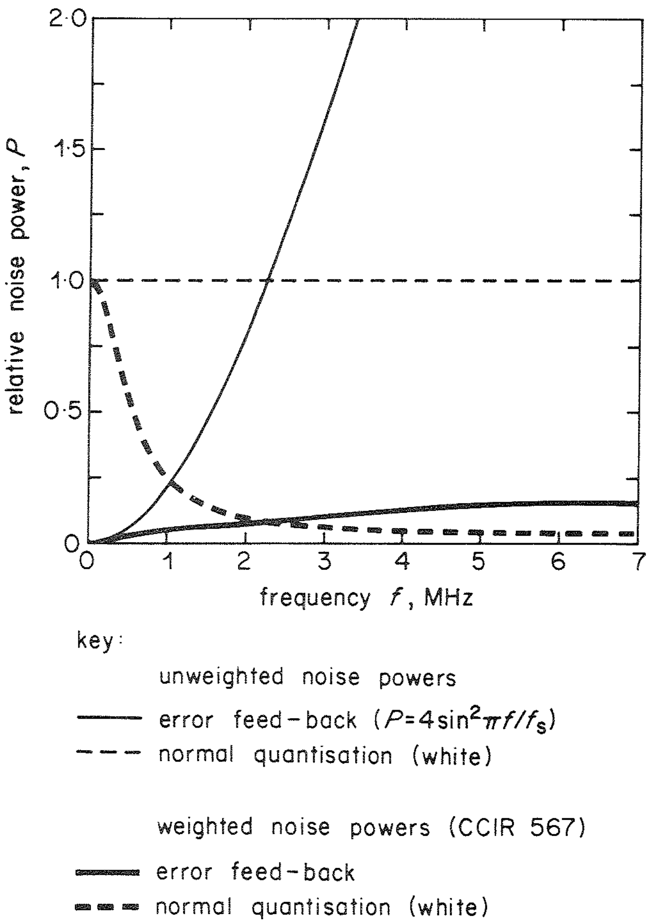
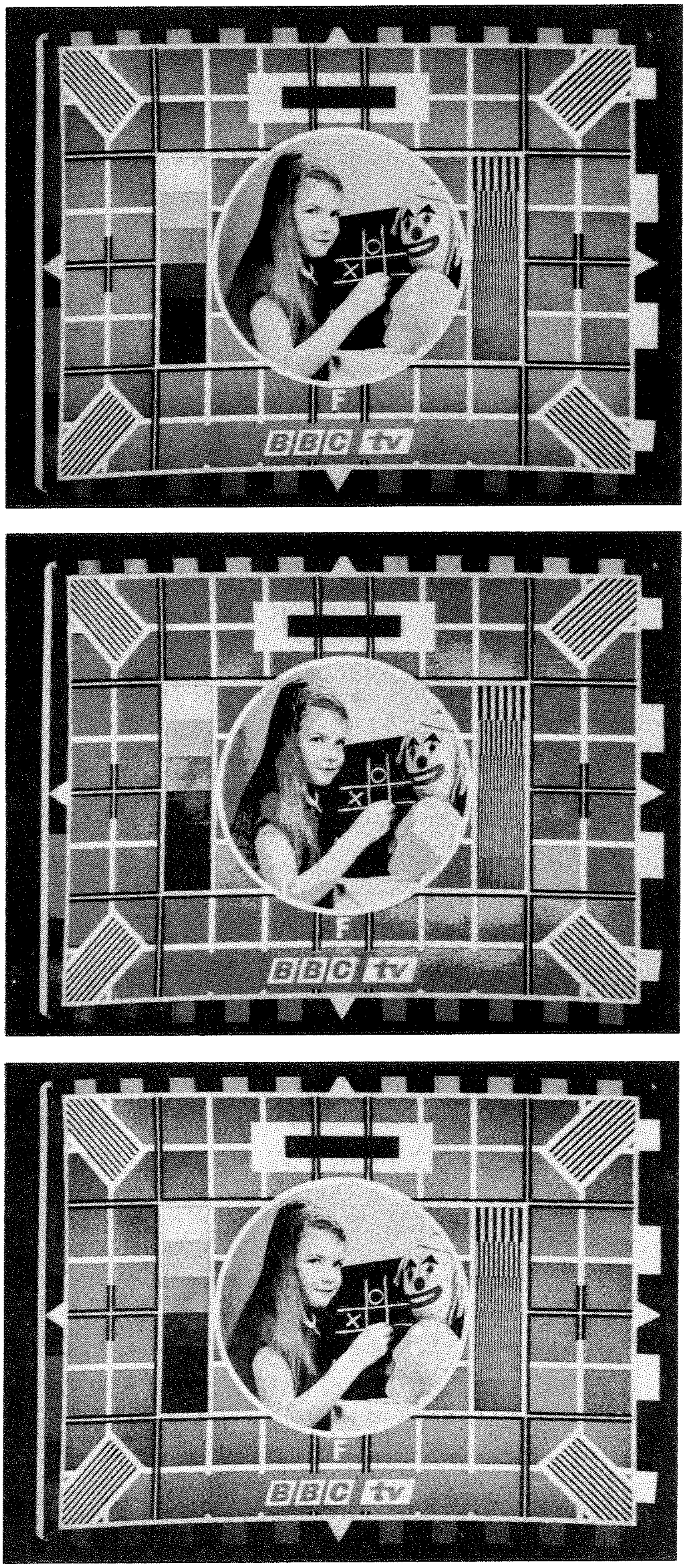


Fig. 5 - Quantisation noise spectra for a sampling rate $f_s = 13.5$ MHz.

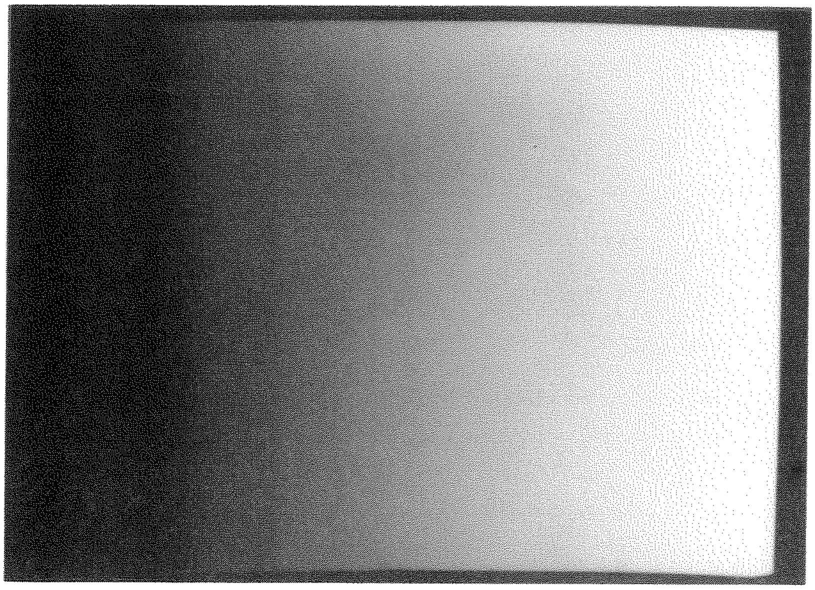


(a) Original

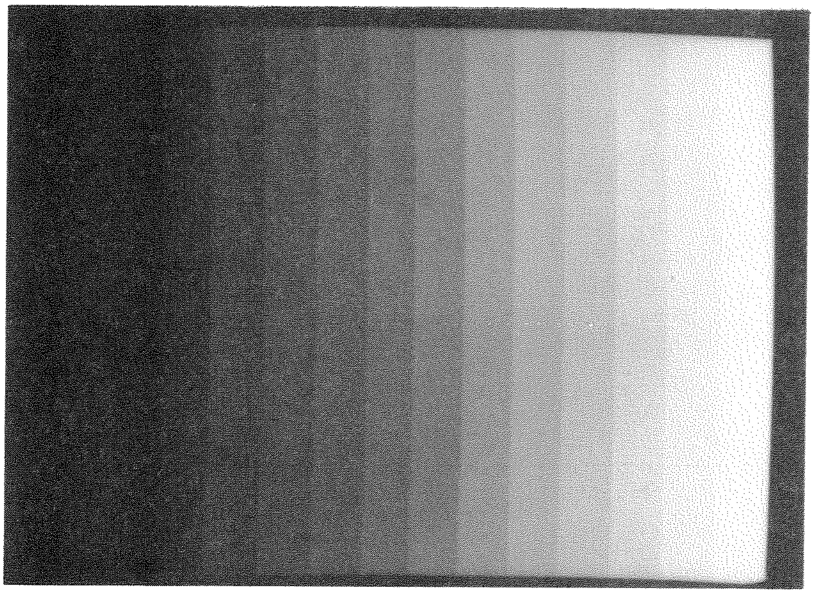
(b) Rounding to 3 bits by simple truncation

(c) Rounding to 3 bits by error feedback

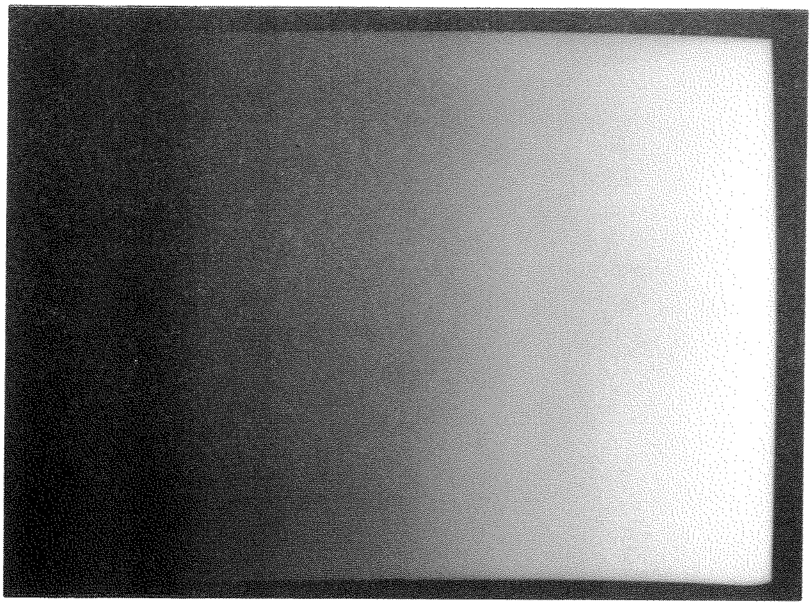
Fig. 6 - Coarse quantisation of a test-card signal.



(a) Original

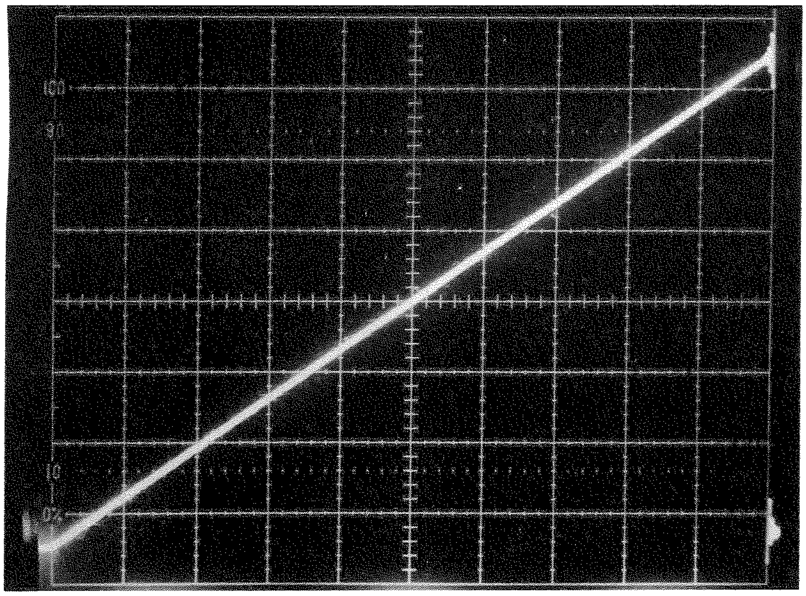


(b) Rounding to 4 bits by simple truncation

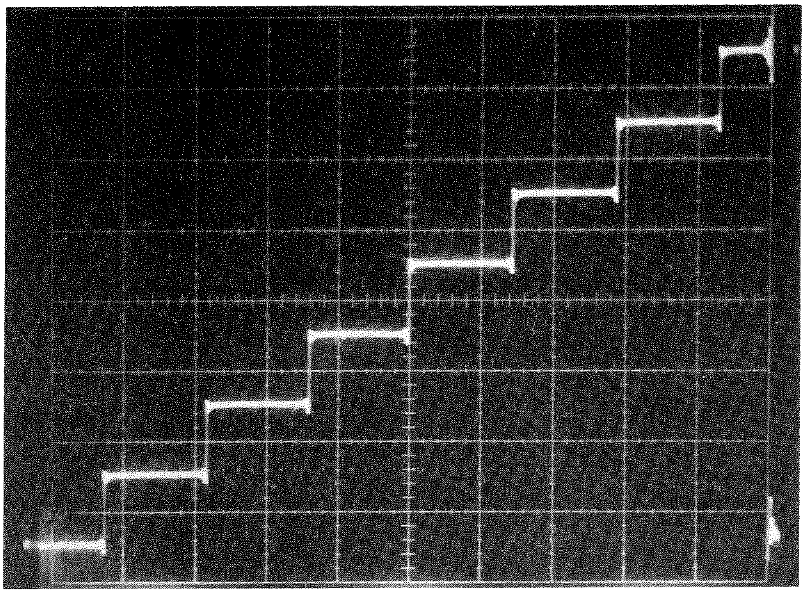


(c) Rounding to 4 bits by error feedback

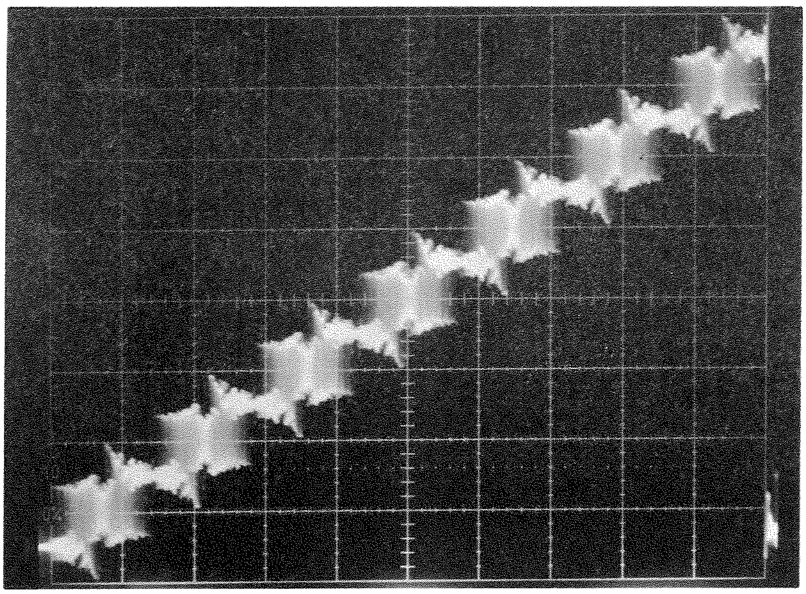
Fig. 7 - Coarse quantisation of a ramp signal.



(a) Original



(b) Rounding by simple truncation



(c) Rounding by error feedback

Fig. 8 - Waveforms of a coarsely quantised ramp.

4. APPLICATIONS

4.1 General

Error feedback circuits have been applied successfully in a wide range of applications for both digital video processing circuits and digital video signal generators.

4.2 Digital video processing circuits

One of the earliest applications for an error feedback circuit was in a digital video noise reducer[6] where the schematic given in Fig. 9 shows a processing path in which 16 bits are generated in internal processing. For circuit economy, these are rounded to 8 bits at a point where a second 8-bit digital video signal is added to the 8 most significant bits. In this case the additional circuit complication was minimal but the effect on the performance of the noise reducer was substantial.

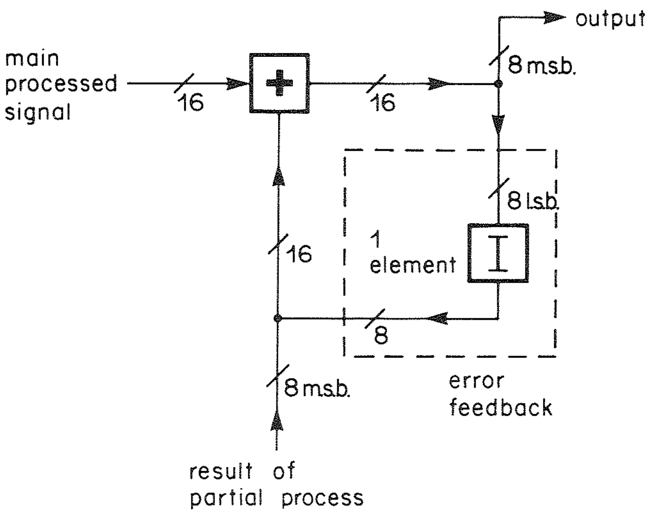


Fig. 9 - Output circuit of noise reducer showing error feedback.

A television animation store system[7,8] makes widespread use of error feedback to allow the signal to be conveyed between processing units using 8-bit digital video busses. Moreover, error feedback is used to reduce the data from 8 bits to 7½ bits per sample (i.e., alternately 7 bits and 8 bits) so that the signal can be stored using a disc drive which could not provide the necessary data rate to record the full 8-bit signal[9]. The circuit used to do this is reproduced here as Fig. 10.

Further examples of where error feedback techniques have been successfully applied include the 'Slide File'* studio stills store[10] which includes a cross-fade mixer which has been found to give entirely satisfactory results. Where systems which include digital video mixers and cross faders are designed within the BBC they normally include the error feedback method of accommodating residual portions of the faded digital video signal.

4.3 Digital Electronic Picture Generation

Where a signal is generated as a plain area which can be adequately described using a constant coded level it is unnecessary to additionally generate an error feedback-like signal unless it is intended that the level of the plain area should be between quantum steps.

Ramp signals or plain areas whose value lies between quantum steps should be generated with more than 8 bits and rounded, using error feedback arithmetic. Staircase signals can, of course, be generated where required using 8 or fewer bits.

* Slide File is manufactured and marketed by Rank Cintel.

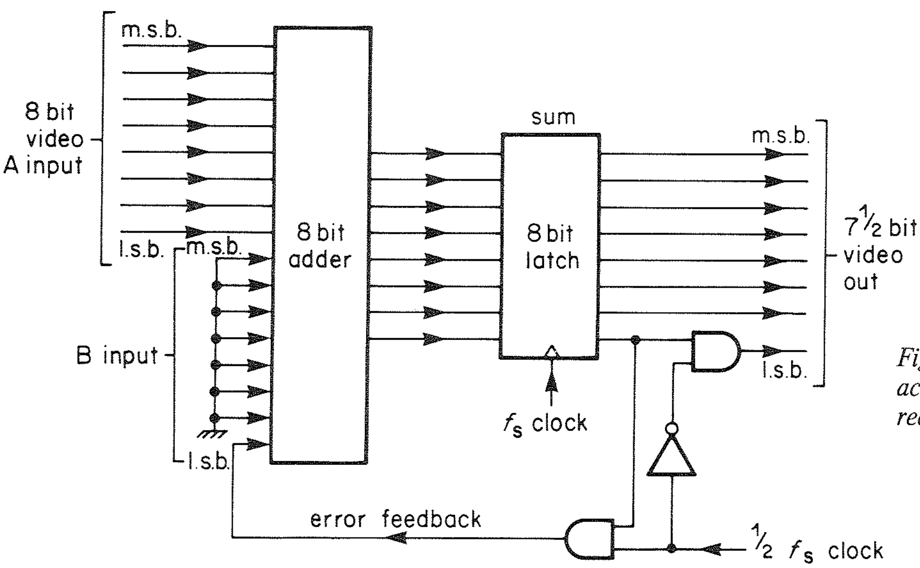


Fig. 10 - Circuit to reduce quantisation accuracy for 8 bits to 7½ bits for recording using a disc drive with limited data rate.

5. DISCUSSION

In the illustrations shown earlier in Section 3, signals were reduced to 3 or 4 bits in order to magnify the effects of error feedback and simple truncating thus allowing them to be clearly presented in this Report. With a reduction to 8 bits, similar effects occur but at a very much lower level which is below the threshold of visibility for error feedback rounding but not for simple truncation. Where the result of applying error feedback produces a noise-like effect, the weighted signal-to-noise ratio in a 5.0 MHz bandwidth is approximately 67.9 dB which is about 18 dB below the threshold of visibility for random Gaussian noise.

Experience has shown that when colour difference signals are quantised the effects generated are less visible than with luminance signals. However, error feedback also needs to be applied when colour difference signals are rounded to 8 bits to avoid generating contours which may become visible under critical conditions.

Although error feedback provides a convenient method of eliminating contouring effects produced by digital processing operations, it is not easily applied to the original A/D conversion process. However, any contouring produced by A/D conversion may be removed if necessary by dither signals[11] added to the analogue video signal. A half-sampling frequency dither signal is particularly beneficial as it effectively doubles the number of quantum levels in plain areas of the picture without any penalty. Any remaining contouring may finally be removed by adding a psuedo-random component to the dither signal. Note however that for picture sources, other than electronic signal generators, sufficient dither is normally provided by the inherent random noise generated by the source. Thus means are available for eliminating contouring effects in any part of an 8-bit digital video chain.

Despite the usefulness of error feedback, it is important that the number of occasions where a reduction down to 8 bits occurs should be kept to a minimum as each occasion introduces extra quantising noise. Thus operations which generate additional low order bits such as filtering and mixing should be performed to a greater accuracy than 8 bits up to the point where practical requirements, such as the need to transmit the signal to a separate piece of equipment, dictate a reduction to 8 bits. Additionally, intelligent partitioning of equipment is required. For example, key signals should be normalised to fill the full 8-bit conversion range before being transmitted from a key generator to a mixer.

It may be noted that video mixers are normally operated at full or zero gain in which case no quantising noise is added since no additional bits are generated. This contrasts markedly with digital audio processing where faders are not normally operated at full gain and a large number of mixing operations are often applied to a given signal.

6. CONCLUSIONS

In mathematical operations where it is either necessary or convenient to convey a mathematical result with fewer significant digits than are originally generated rounding techniques may be employed to ensure no systematic error is introduced. The generation of unwanted artifacts when critical digital video signals are simply truncated is evidence that an efficient rounding technique must be employed in the digital video processing to avoid systematic errors which visibly distort the signal.

An error feedback rounding technique has been described which very significantly reduces the visibility of contouring type quantising errors which can be generated in digital video processing operations by truncating resultant signals down to 8 bits. This removes the highly visible coherent low frequency quantisation distortions and replaces these with much less visible high frequency components.

This technique requires few extra components compared to simple truncation and has been successfully applied in digital video processing equipment designed by BBC engineers since 1974.

7. RECOMMENDATIONS

It is recommended that CCIR Rec. 601 should include a note stating that an efficient rounding technique such as that provided by error feedback should be employed in any process where fractional bits are generated and then reduced to the standard 8 bits.

8. REFERENCES

1. UK Patent No. 1 455 821, 17th Sept. 1976.

2. CUTLER, C.C. 1960. Transmission Systems Employing Quantisation. US Patent 2927962, March 8, 1960.

3. KIMME, E.G. and KUO, F.F. 1963. Synthesis of Optimal Filters for a Feedback Quantisation System. IEEE Trans. on Circuit Theory, **CT-10**, September 1963, pp 405-413.

4. BRAINARD, R.C. 1967. Subjective Evaluation of PCM Noise-feedback Coder for Television. Proc. IEEE, **55**, 3, March 1967, pp 346-352.

5. WESTON, M. 1975. Error Feedback to Reduce the Visibility of Quantisation. BBC Research Dept. Internal Memo. August 1975.

6. DREWERY, J.O., STOREY, R., and TANTON, N.E. 1984. Video Noise Reduction. BBC Research Department Report No. BBC RD 1984/7.

7. CROLL, M.G. 1980. The General Design of a Digital Stills Storage System for use with an Electronic Rostrum Colour Camera. BBC Research Department Report No. BBC RD 1980/13.

8. DEVEREUX, V.G. 1984. Television Animation Store: digital chroma-key and mixer units. BBC Research Department Report No. BBC RD 1984/16.

9. DUREY, A.J. 1984. Television Animation Store: recording pictures on a parallel transfer magnetic disc. BBC Research Department Report No. BBC RD 1984/17.

10. WESTON, M. 1986. Development of Slide File — A Digital Store for TV Stills. BBC Research Department Report No. BBC RD 1986/10.

11. DEVEREUX, V.G. Application of PCM to Broadcast Quality Video Signals. The Radio and Electronic Engineer, No. 7. July 1974. pp 373-381, and No. 9, September 1974, pp 463-472.